Status and challenges of EUV Lithography

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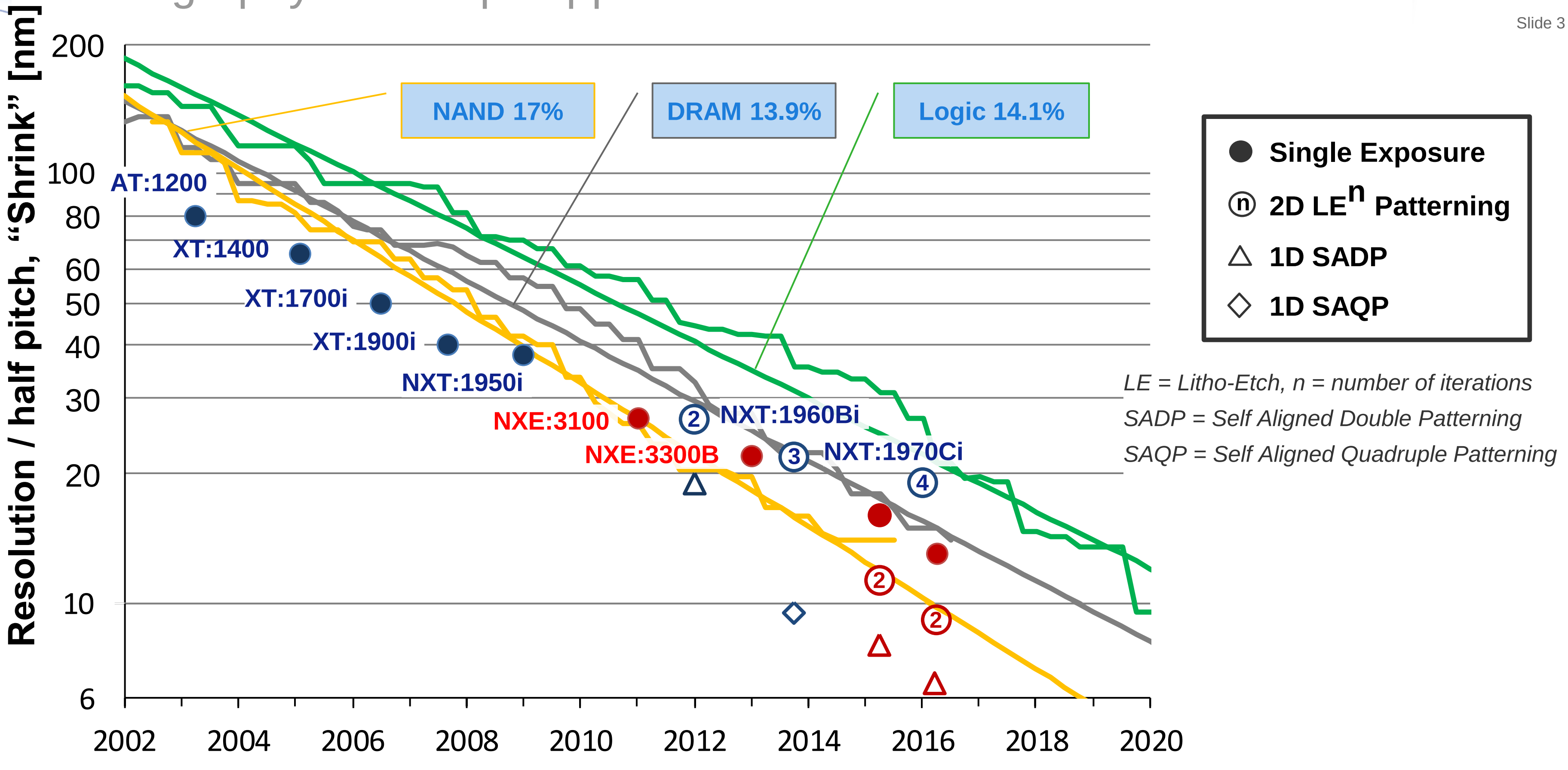
NXE:3300B

Summary and acknowledgements

Industry roadmap towards < 10 nm resolution

Lithography roadmap supports continued shrink



** Note: Process development 1.5 ~ 2 years in advance*

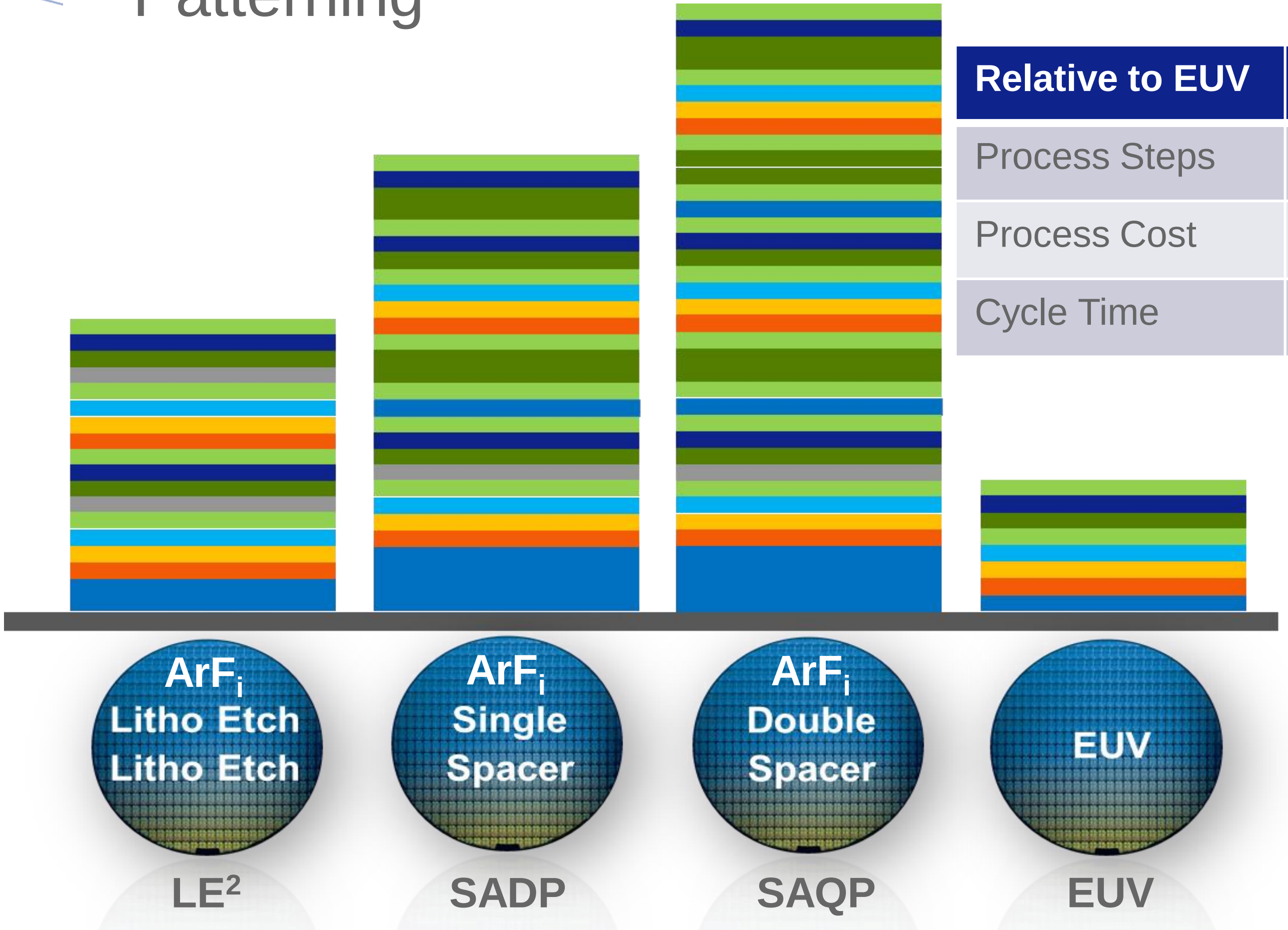
EUV reduces Cost and Cycle Time vs. Multiple Patterning

Relative to EUV	LE^2	SADP	SAQP
Process Steps	x2	x4	x5
Process Cost	+10%	+30~50%	+>50%
Cycle Time	x2	x4	x5

LE = Litho-Etch, n = number of iterations

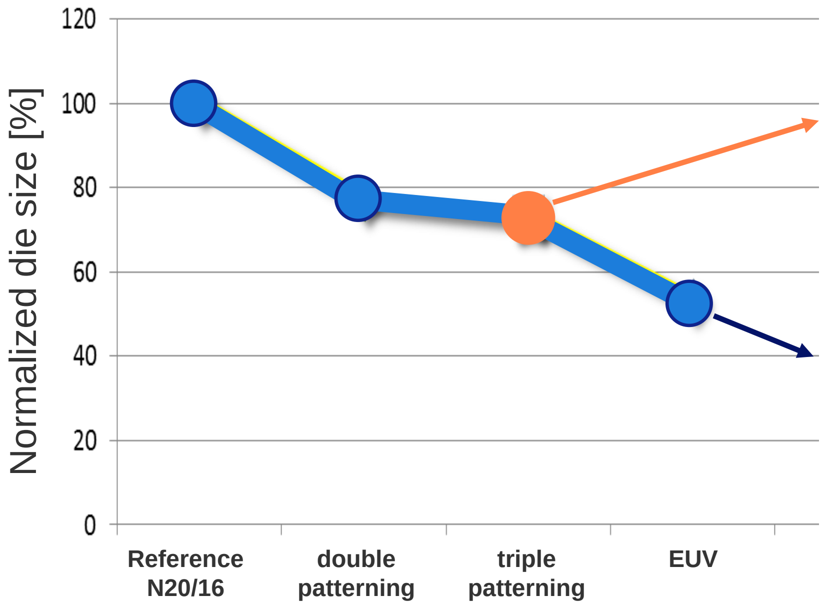
SADP = Self Aligned Double Patterning

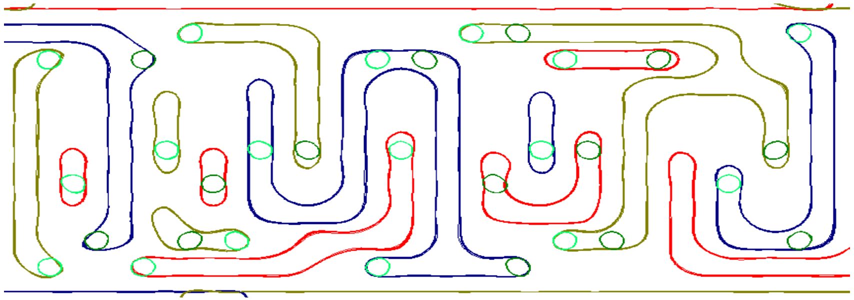
SAQP = Self Aligned Quadruple Patterning



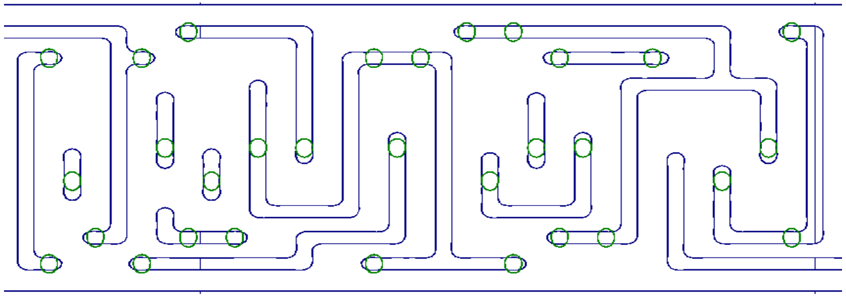
EUV enables 50% Scaling for the 10 nm node

Layout restrictions and litho performance limit shrink to ~25% using immersion





Triple patterning does not show a process window

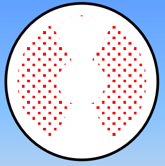


EUV meets all litho requirements

Source: ARM, Scaled 20nm flip-flop design

NXE technology roadmap has extendibility to <7nm

					Under study			
Resolution [nm]	**32**	**27**	**22**	**16**	**13**	**10**	**7**	**<7**
Wavelength [nm]	13.5							
Lens – NA	0.25		0.33			0.33NA DPT		>0.5 DPT
		NXE:3100	NXE:3300B					
Lens – flare	8%		6%	4%				
Illumination – coherence	σ=0.5	σ=0.8	σ=0.2-0.9	Flex-OAI	Extended Flex-OAI			
					reduced pupil fill ratio			
Overlay – DCO [nm]	7	4.0	3.0	1.5	1.2	1.0		
Overlay – MMO [nm]	-	7.0	5.0	2.5	2.0	1.7		
TPT (300mm) – Dose [mJ/cm²]	5	10	15	15	20	20		
TPT (300mm) – Power [W]	3	10 - 105	80 - 250	250	250	500		
TPT (300mm) – Throughphut [w/hr]	-	6 - 60	50 - 125	125	125	165		



pupil fill ratio defined as the bright fraction of the pupil

ASML's NXE:3100 and NXE:3300B

	NXE:3100	NXE:3300B
NA	0.25	0.33
Illumination	Conventional 0.8 σ	Conventional 0.9 σ Off-axis illumination
Resolution	27 nm	22 nm
Dedicated Chuck Overlay / Matched Maching Overlay	4.0 nm / 7.0 nm	3.0 nm / 5.0 nm
Productivity	6 - 60 Wafers / hour	50 - 125 Wafers / hour
Resist Dose	10 mJ / cm2	15 mJ / cm2

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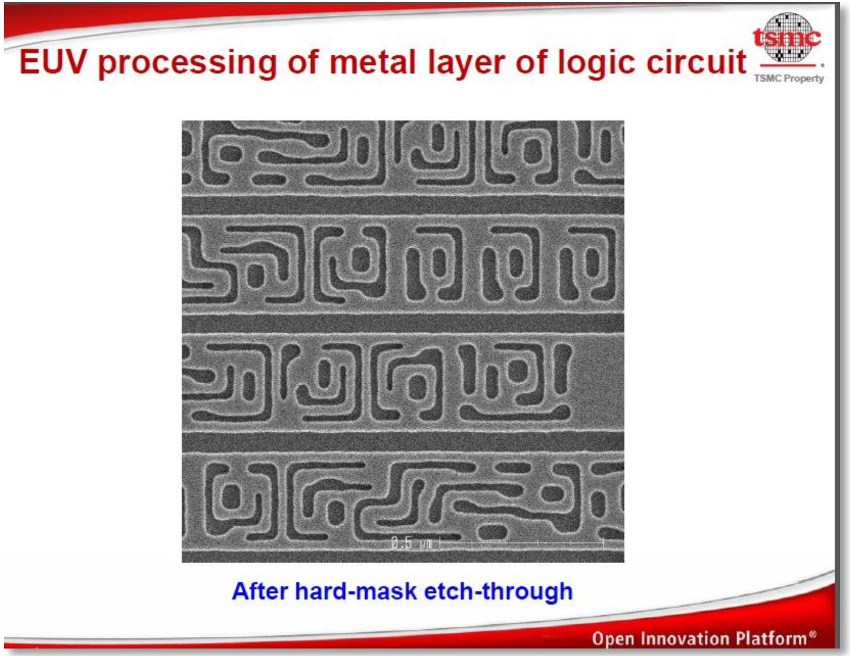
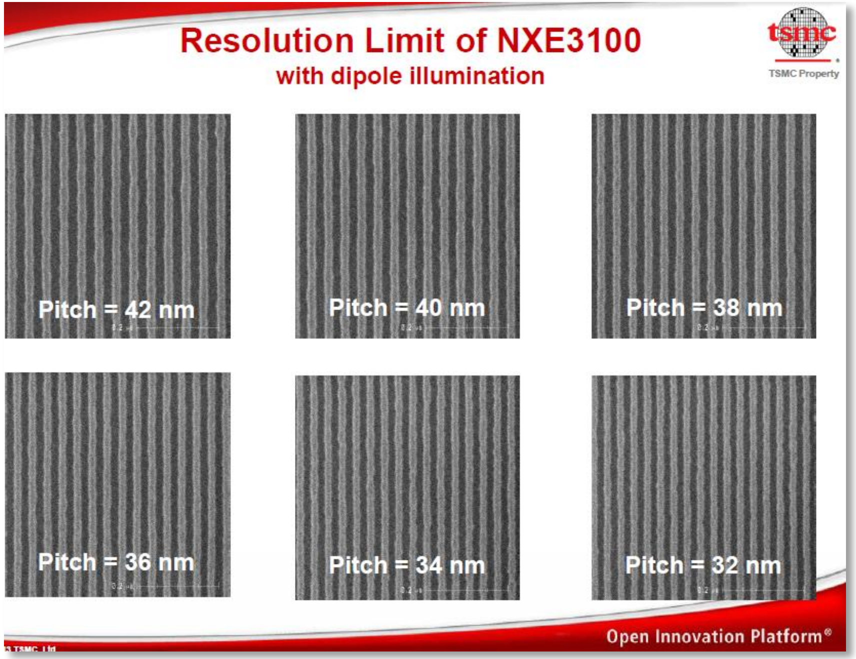
NXE:3100 in use at customers for cycles of learning



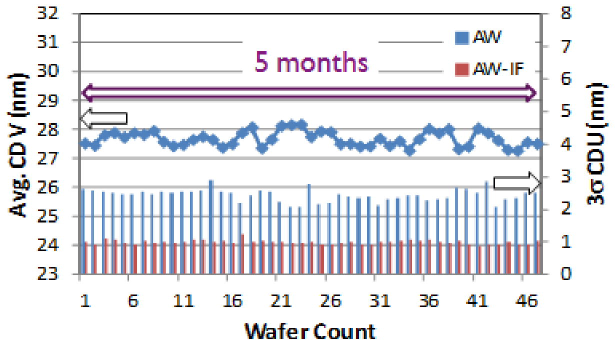


Data courtesy of TSMC

NXE:3100 shows stable performance

LONG TERM WAFER STABILITY OF 27nm V LS - NOV'12-APR'13, CONV.ILL. 14MJ/CM2, YIELDSTAR S200

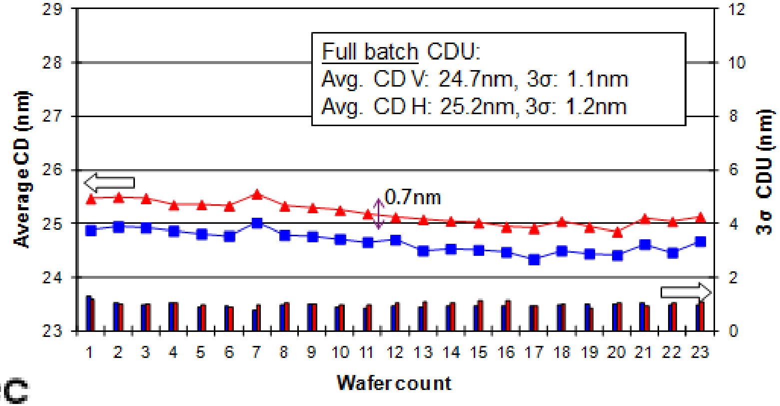
71 fields/wafer, 26x33mm^2, 5x3 intrafield sampling



imec

FULL BATCH CD UNIFORMITY OF 27nm LS

23 wafers, 83 fields/wafer, 1 point/field, Hitachi CG-4000



imec

Data courtesy of imec

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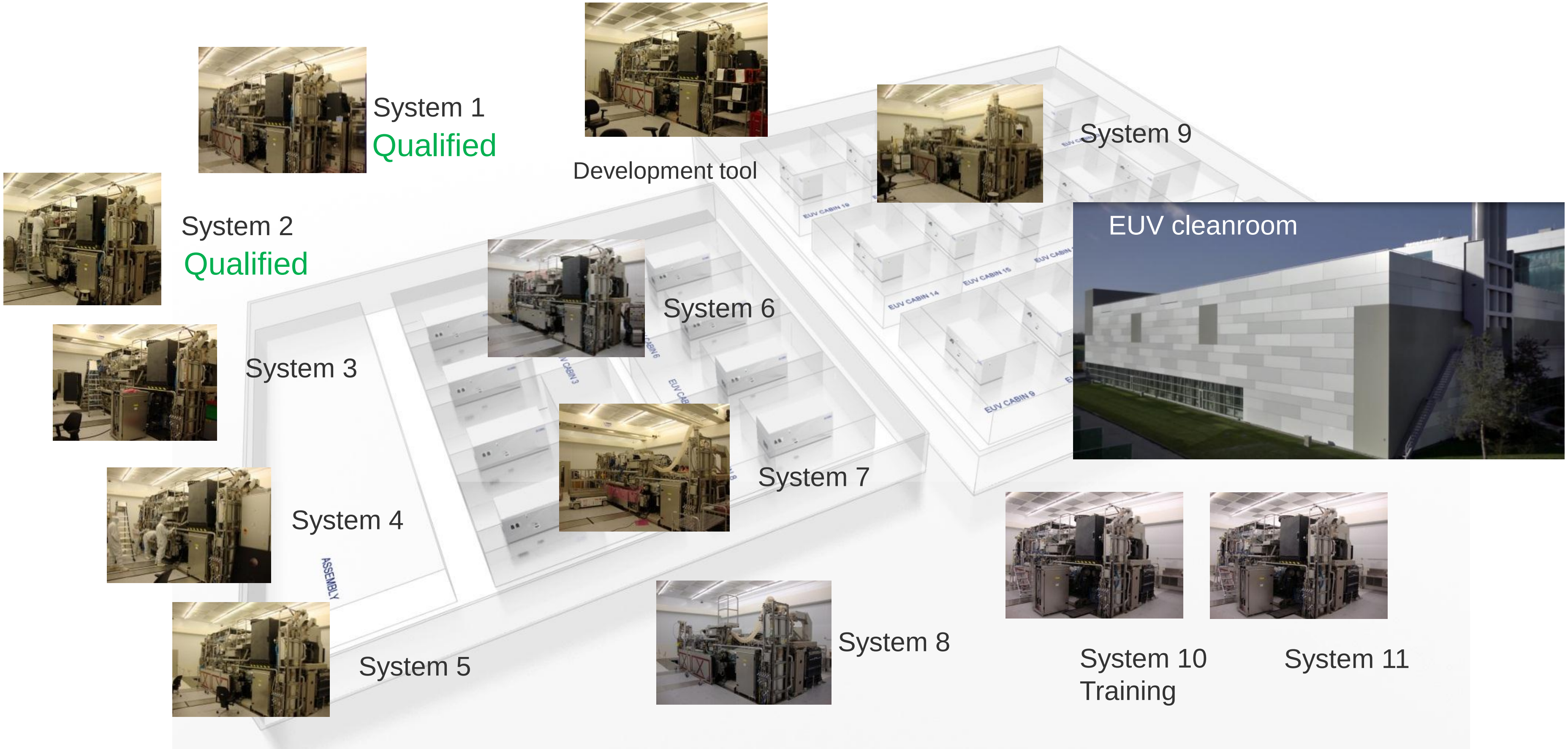
Eleven NXE:3300B systems in various states of integration

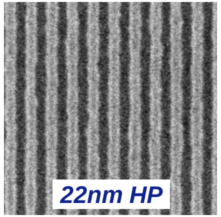


Eleven NXE:3300B systems in various states of integration

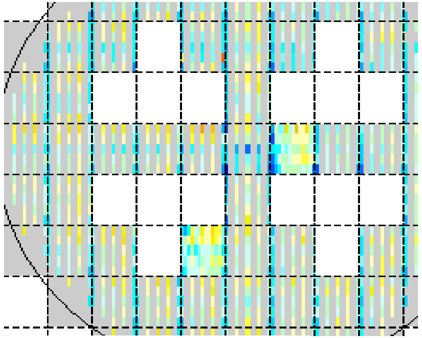
NXE:3300B imaging and overlay beyond expectations

matched overlay to immersion ~3.5nm

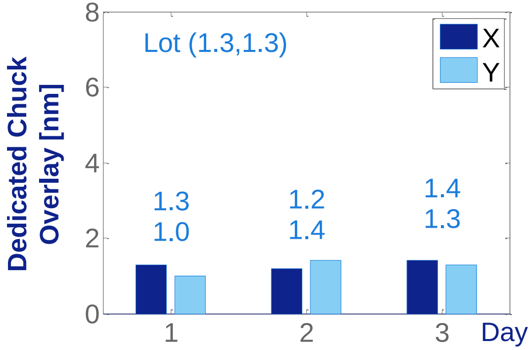
Scanner qualification

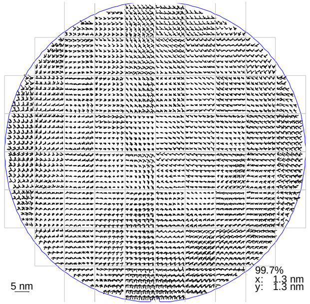


BE = 15.9 mJ/cm^2
EL = 13%
DoF = 160 nm

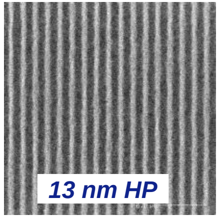


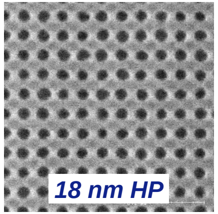
Full wafer CDU = 1.5nm

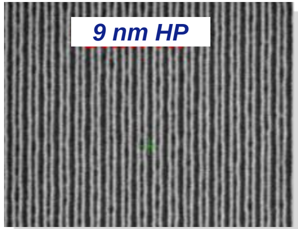




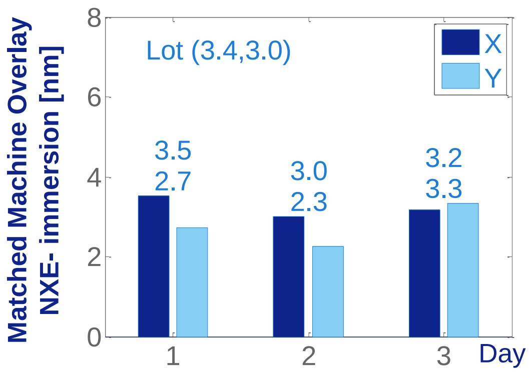
Scanner capability

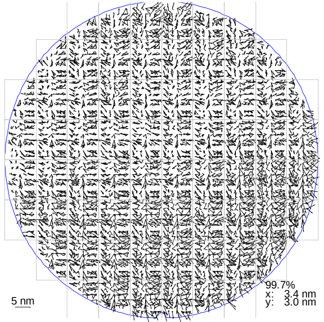






Single exposure   EUV Spacer

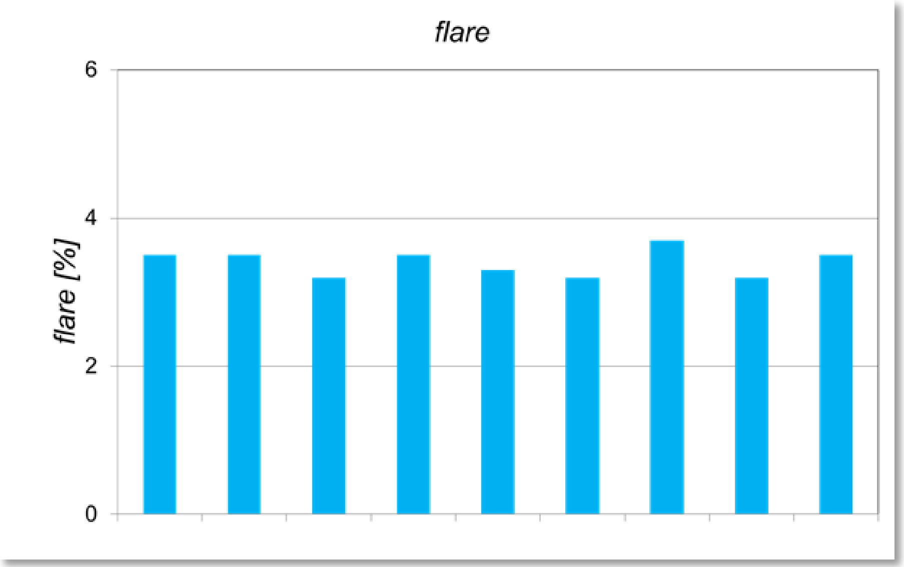


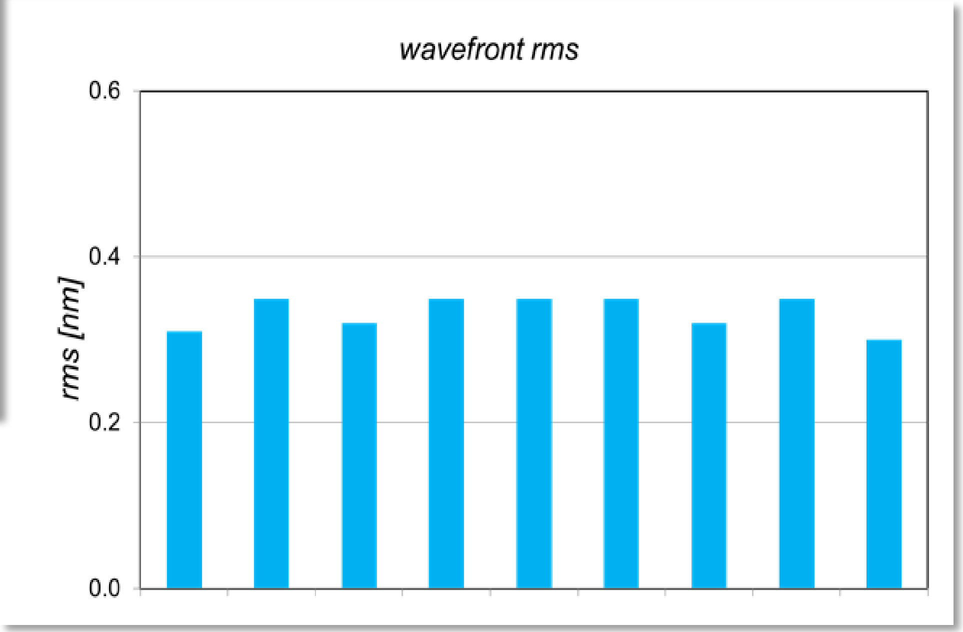


XT:1950i reference wafers
EEXY sub-recipes
18par (avg. field) +
CPE (6 par per field)

Lens performance consistent and exceeds requirements

population for NXE:3300B

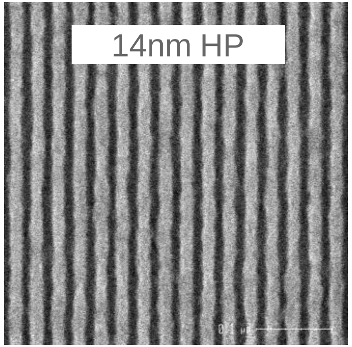


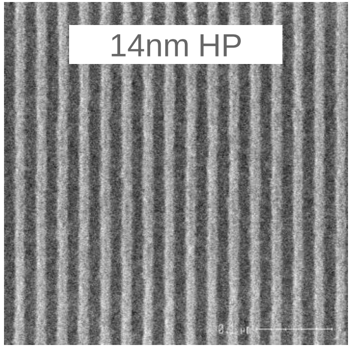


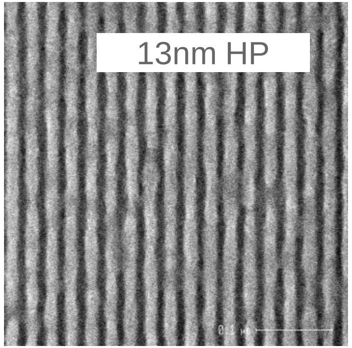
Every bar is an individual lens

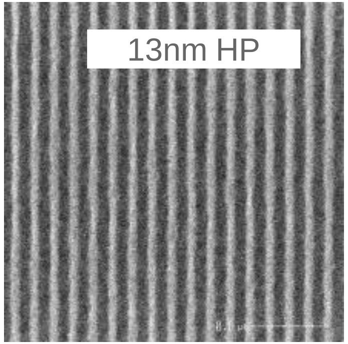
Data courtesy of Carl Zeiss SMT GmbH

Resolution shown on NXE:3300B for dense line spaces, regular and staggered contact holes; all single exposures







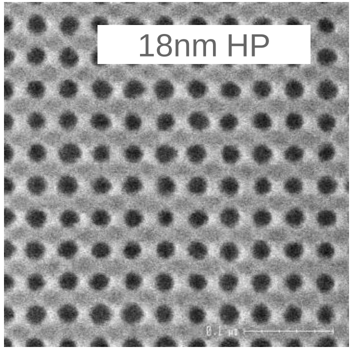


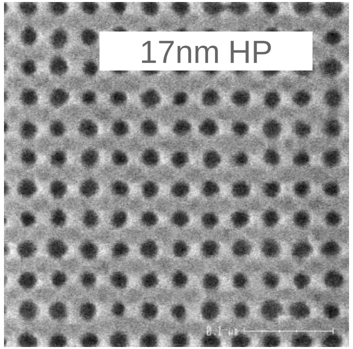
Dipole30,

Chemically Amplified Resist (CAR)

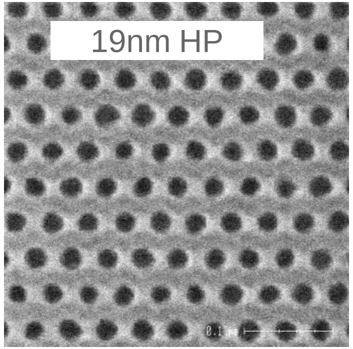
Dipole45,

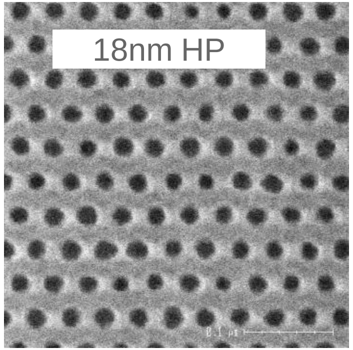
Inpria Resist





Quasar 30 (CAR)





Large Annular (CAR)

NXE:3300B enables single exposure random logic metal layer with large DoF

minimum HP 23 nm (N10 logic cell)

focus

-80nm
-60nm
-40nm
-20nm
0nm
20nm
40nm
60nm
80nm

EUV	ArF immersion
▪ Node: N10 (23nm HP) ▪ 1st insertion point for EUV	▪ Node: N20 (32nm HP)
▪ Single Exposure ▪ Conventional illumination	▪ Double Patterning (design split)
▪ Best focus difference ~10nm	▪ Best focus difference up to 40-60nm
▪ Overlapping DoF current 100..120nm *(expected to improve after further optimization (e.g. OPC))*	▪ Overlapping DoF typical ≈ 60nm

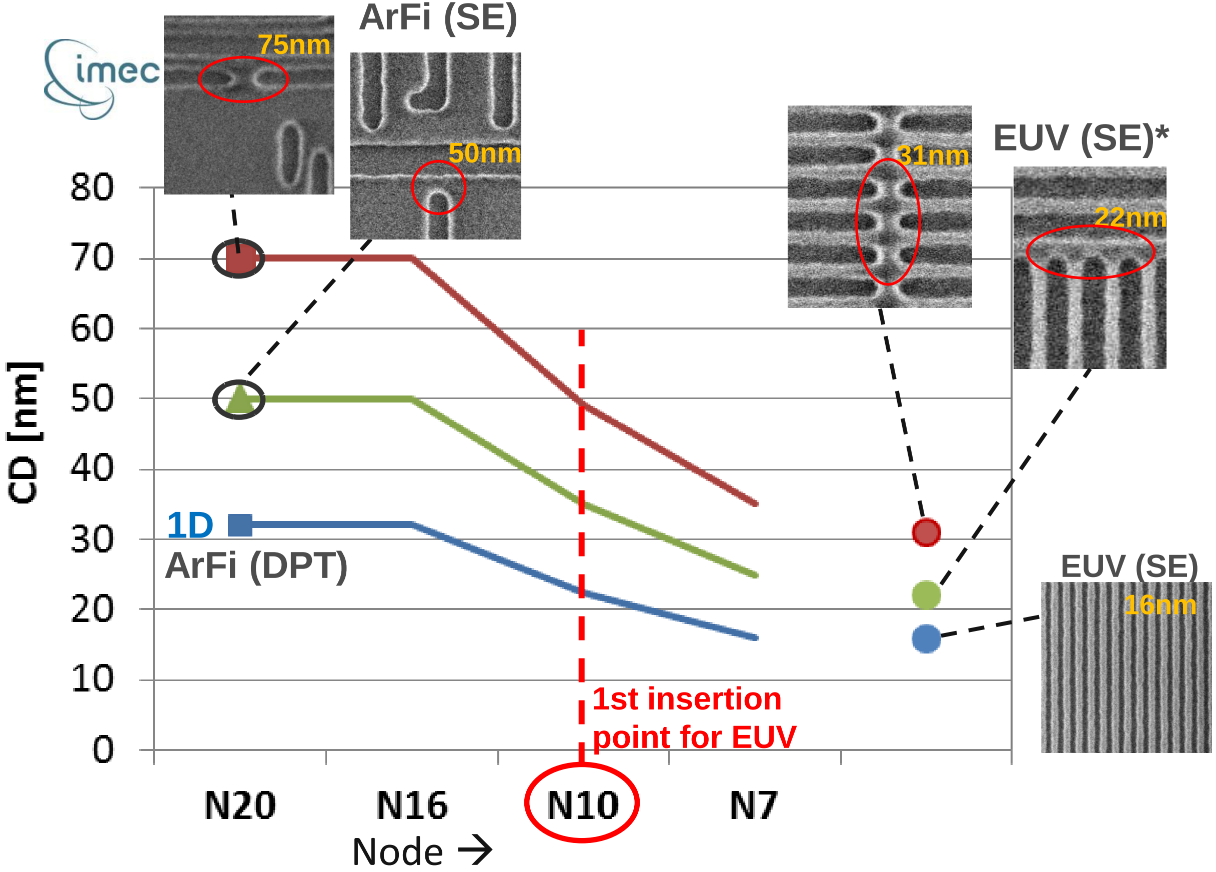
Position in the exposure slit

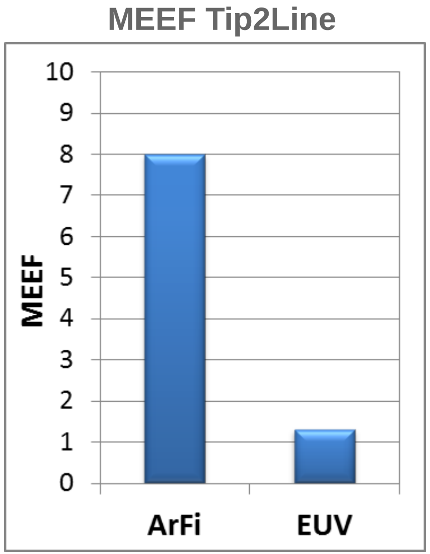
-12mm *0mm* *+12mm*

Excellent print performance over the full exposure slit

EUV enables aggressive shrink on 2D logic

shrink possible beyond N7 node requirement



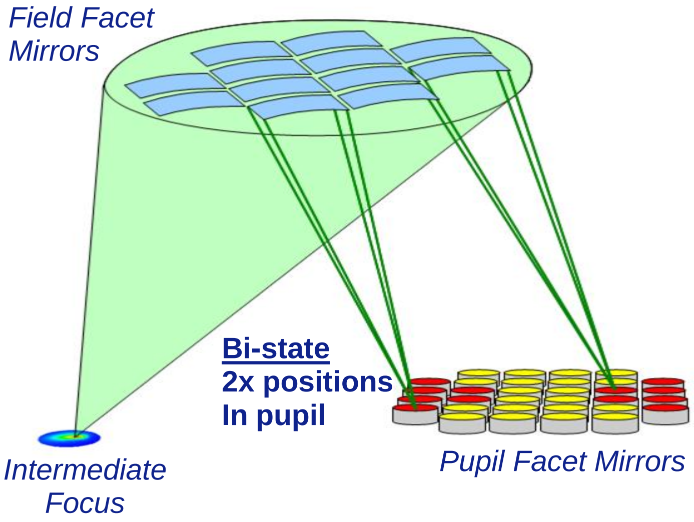


* using high dose resist @ ~50mJ

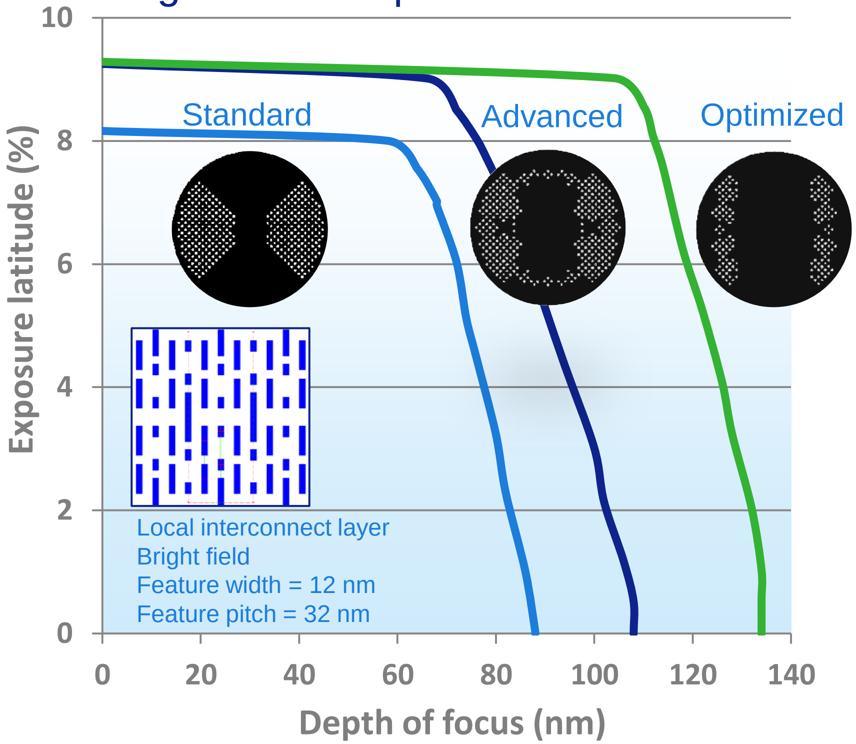
NXE:3300B FlexPupil enhances process window

Enabling further shrink at 0.33-NA

Custom pupil definition enabled by mirror addressing programmability



Logic N7 example

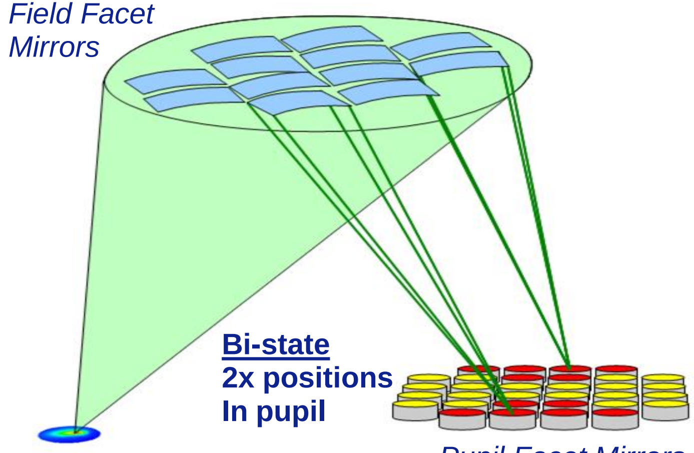


Simulations by Tachyon SMO NXE

NXE:3300B FlexPupil enhances process window

Enabling further shrink at 0.33-NA

Custom pupil definition enabled by mirror addressing programmability



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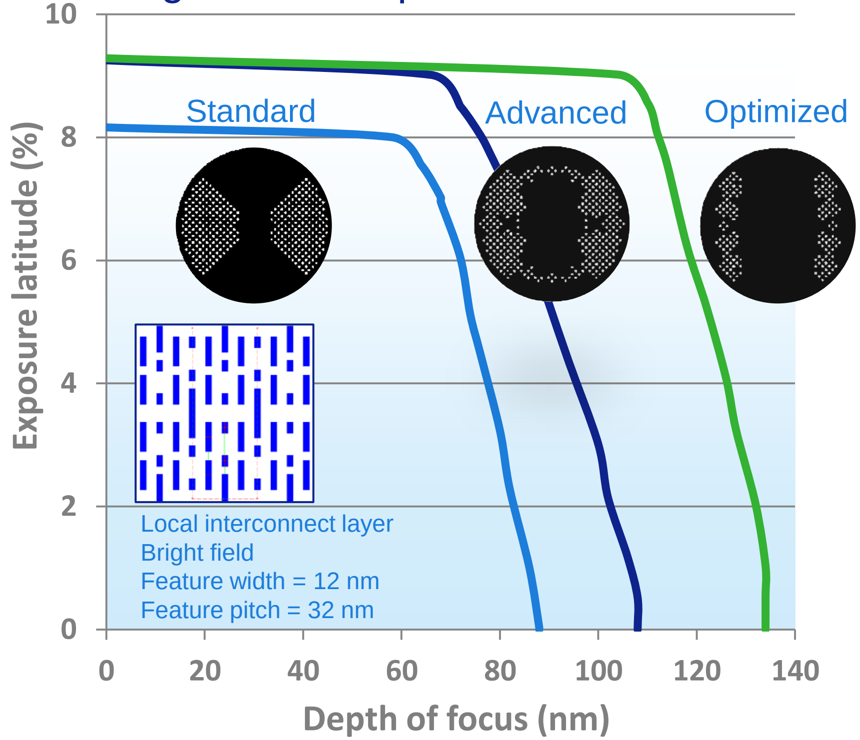
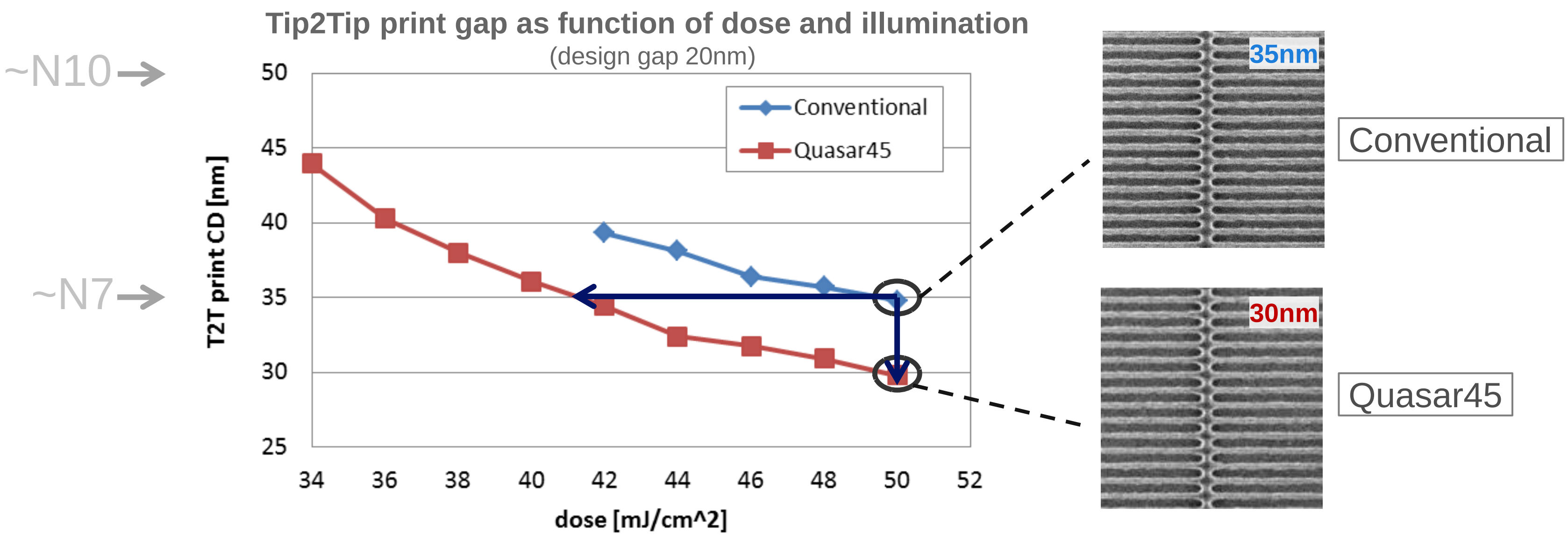


Simulations by Tachyon SMO NXE

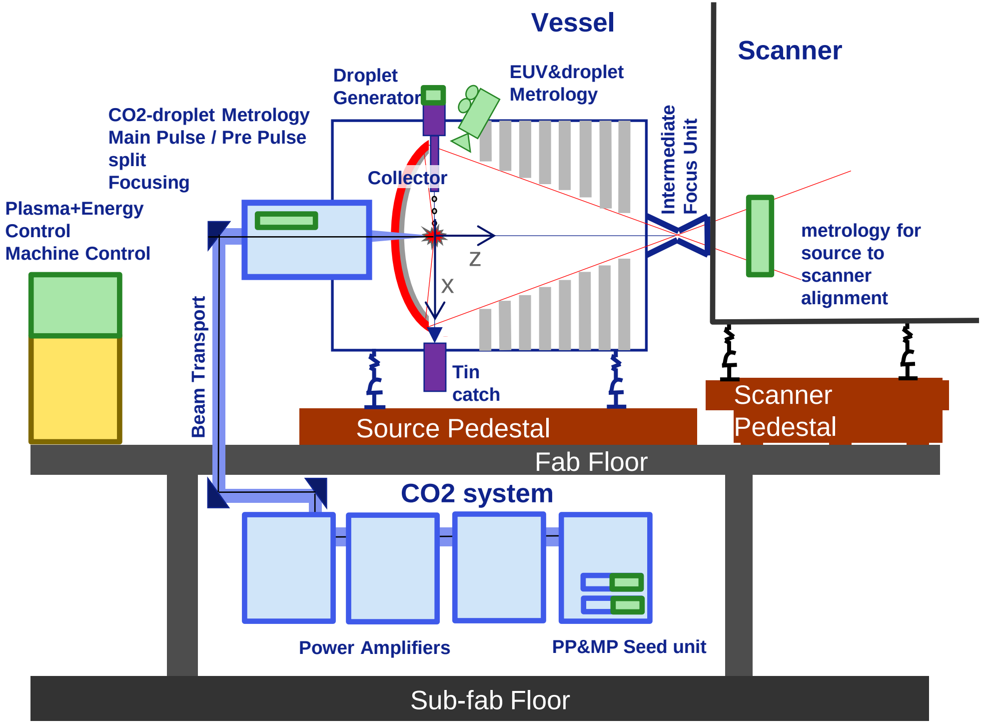
With Off-axis illumination required dose lowered by 16%

tip2tip printed gap size down to ~30nm with Quasar illumination

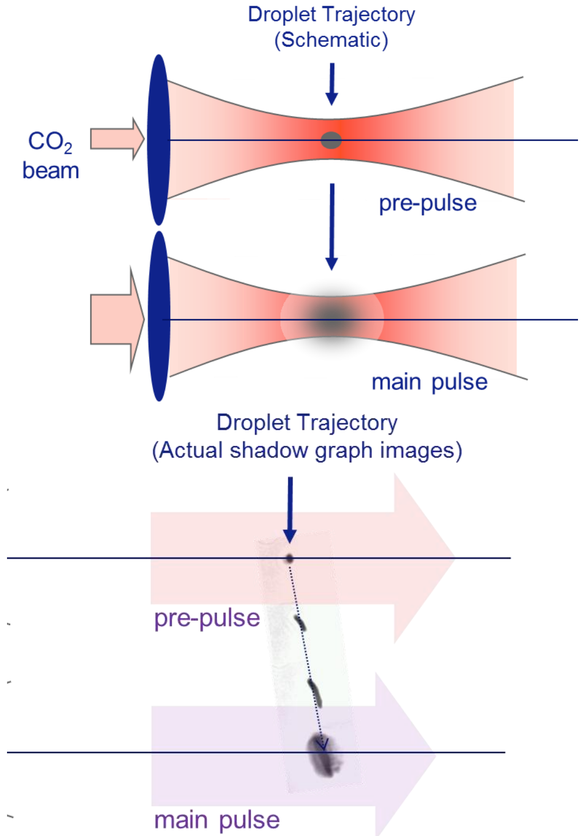


- Tip2tip print gap sizes down to **30nm** with Quasar illumination
- With off-axis illumination
  - printed T2T gap can be reduced on average by ~5nm, as compared to conventional illumination.
  - Printed T2T gap of 35nm can be printed **at ~16% lower dose**, as compared to conventional illumination.

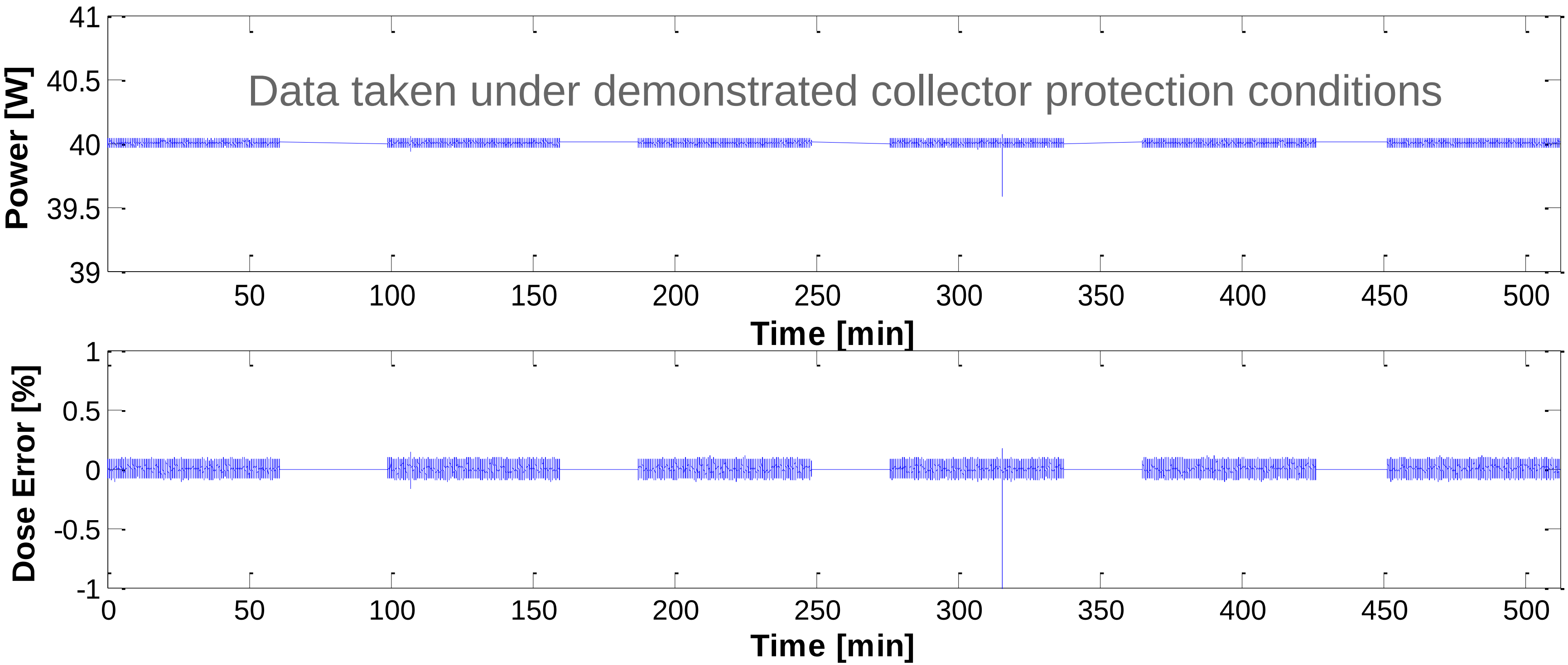
EUV source concept: CO2 drive laser hitting tin droplet, generating a plasma that emits 13.5nm light



Courtesy of Cymer



40W stable dose control performance for six 1-hours for MOPA-PrePulse



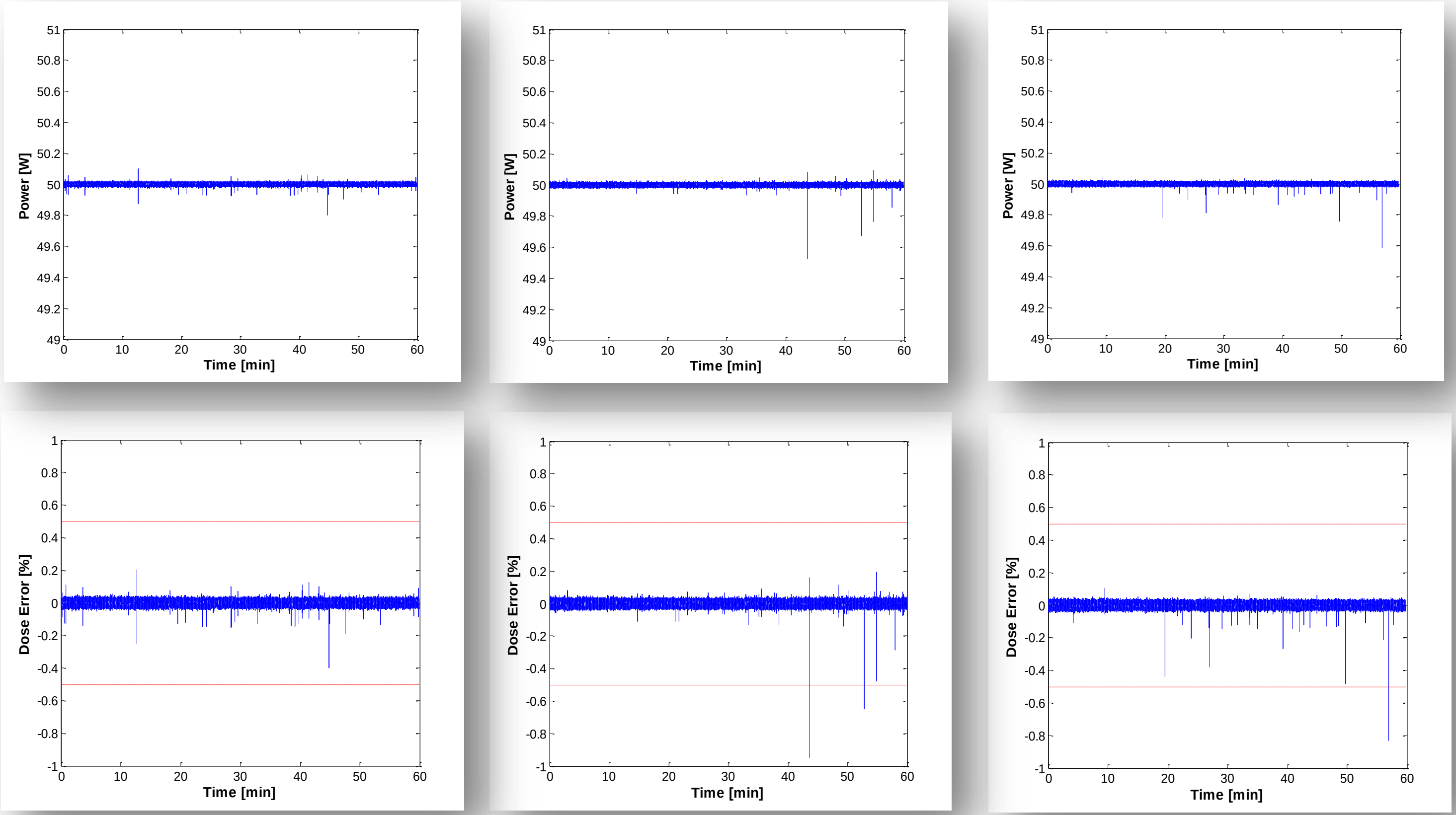
Data courtesy of Cymer

- 196 equivalent wafer exposures with 99.99% die yield

50W MOPA Prepulse EUV Power and Dose Stability

Dose Stability <±0.5%, Die Yield >99.7%

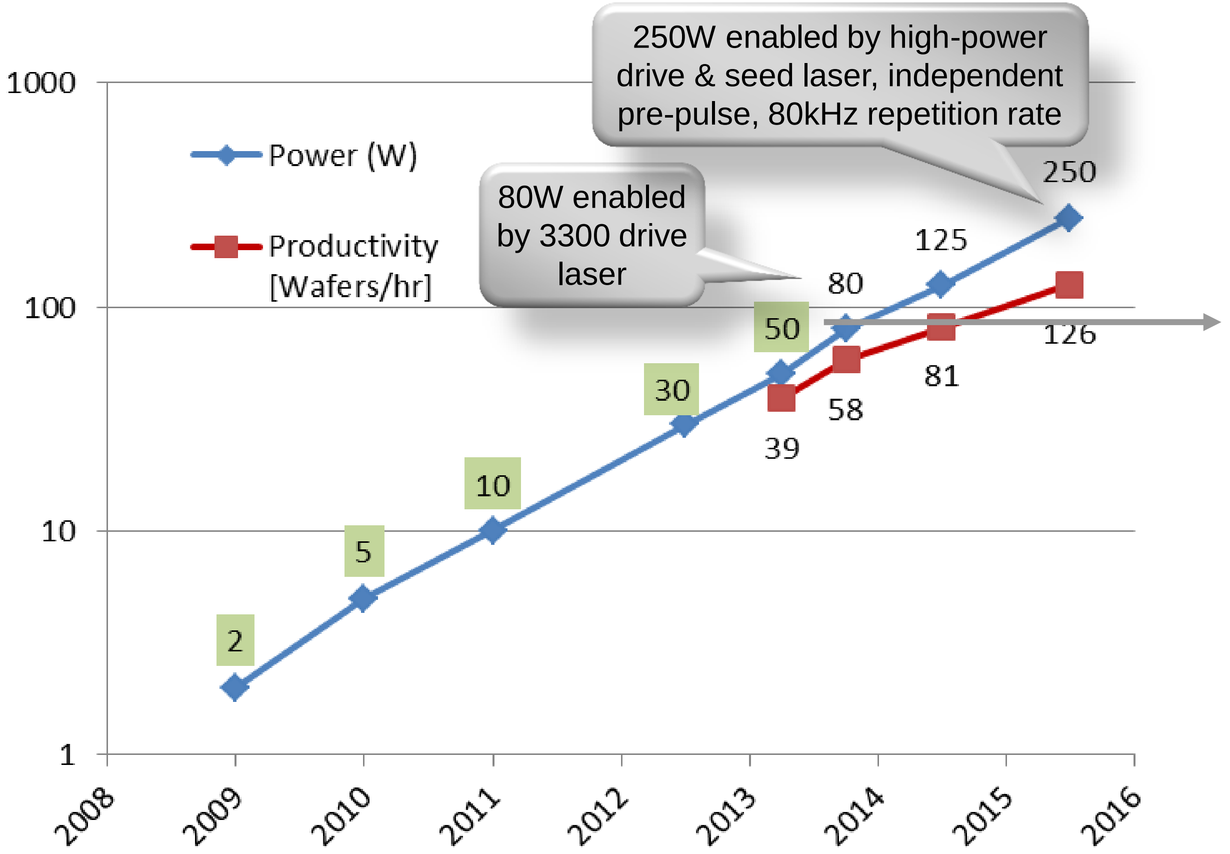
Public

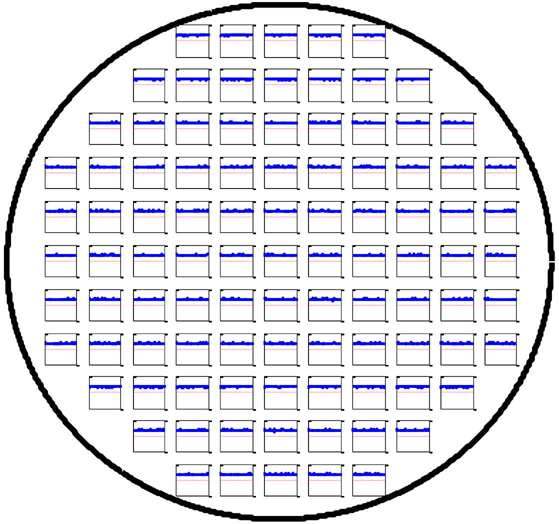


Data courtesy of Cymer

EUV SOURCE POWER PROGRESS

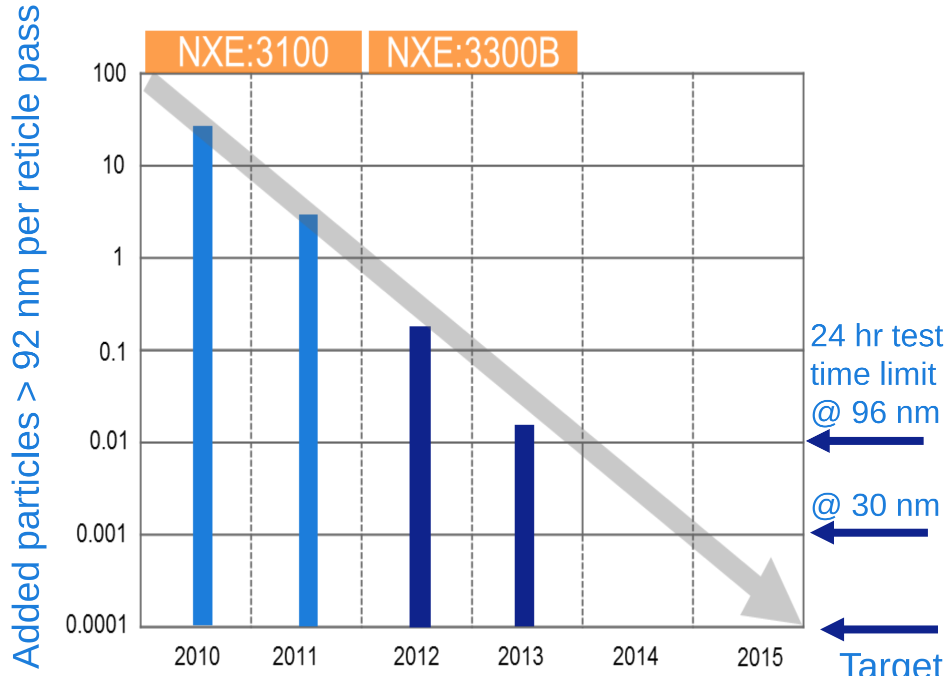
50W Repeatable Power, Dose In Spec, ~40Wafers/Hour,
250W Target To Be Reached In 2015





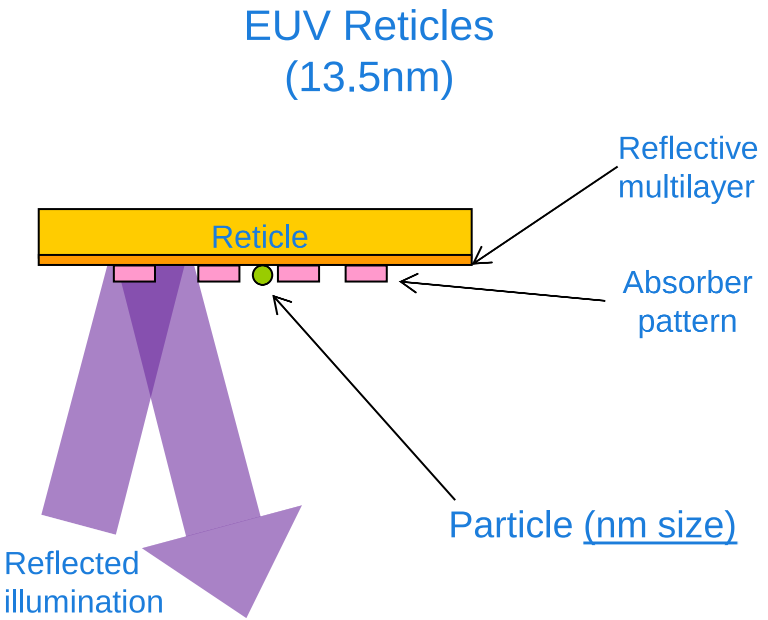
The mask defect challenge

ASML achieved 10x per year improvement for pellicle-less operation (pellicle would reduce defect requirements substantially)



Progress made on ASML machines on added particles per reticle exchange over the past few years

Target performance for full production without pellicle @ 20 nm



The mask defect challenge

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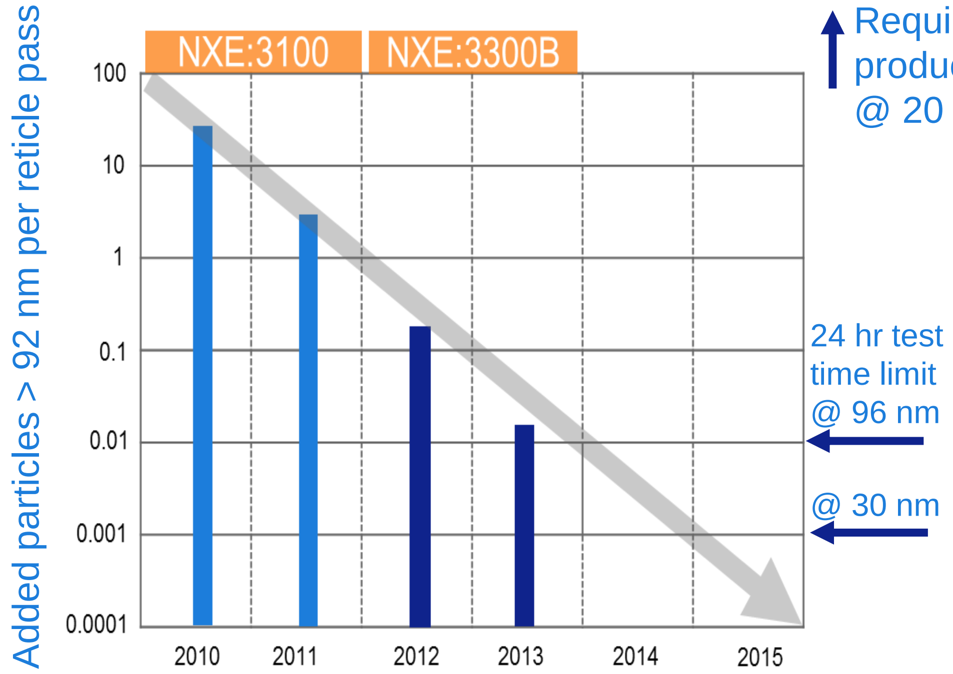
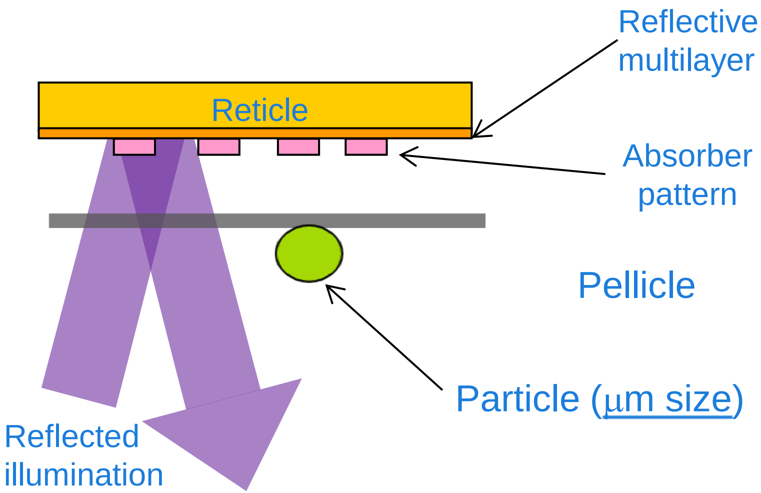
Required for full production with pellicle @ 20 nm

EUV Reticles (13.5nm)





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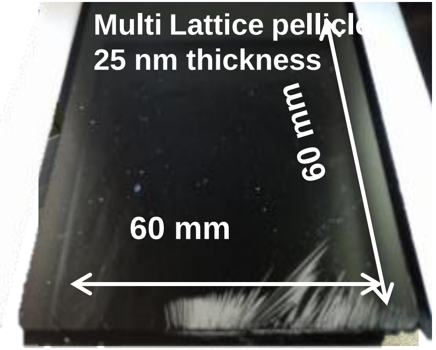
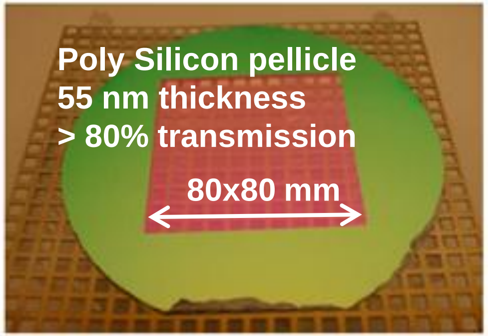
The mask defect challenge

EUV pellicle considered as backup with minimum transmission and imaging loss

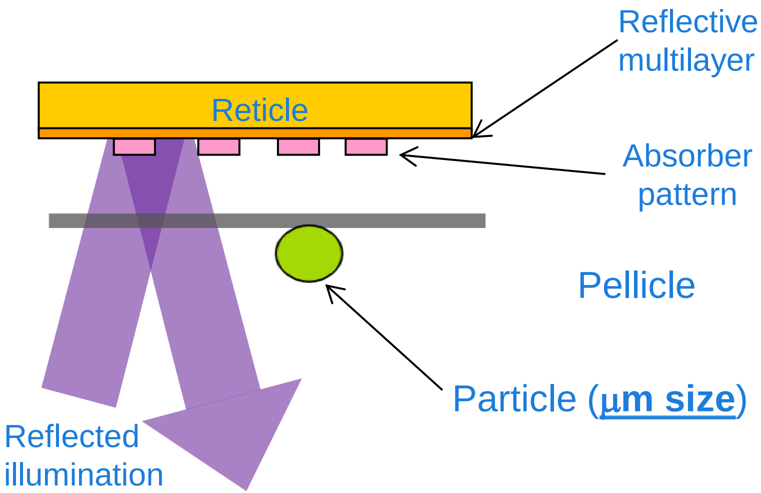




Wafer with **80*80 mm²** membrane

- Target full size
  - 110x144 mm²
- Transmission:
  - Required >90%
  - Achieved ~80%

EUV Reticles (13.5nm)



The mask defect challenge

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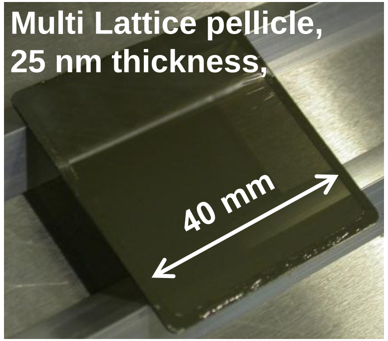

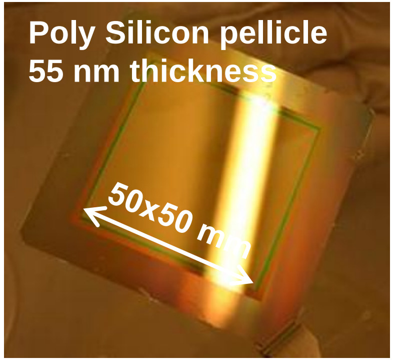

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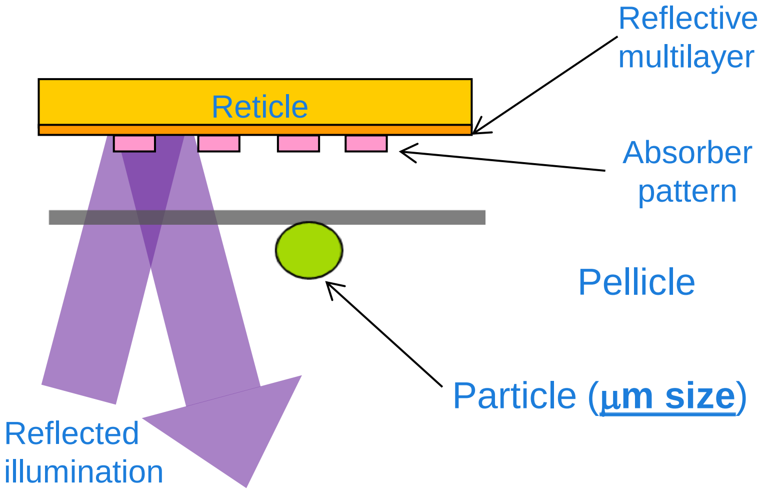

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NXE:3300B
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Conclusions

- Several EUV scanner in use at customer for cycles of learning and showing stable performance
- EUV imaging and overlay performance meets customer requirements for 1x node and below
- Roadmap towards 250W source power enabling exposures at 125 wafers per hour in place
- EUV mask defectivity improvement by 10x/year achieved over past years
    - Target remains to be build a particle free system; pellicle development ongoing as backup solution

Acknowledgements

The work presented today, is the result of hard work and dedication of teams at ASML and many technology partners worldwide including our customers

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